

# Current

## \* Electric current (symbol $I$ )



♥ DEF: the rate at which charge flows past a given cross-section.

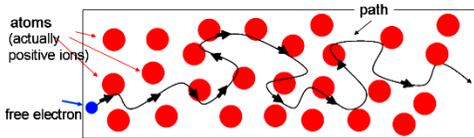
$$I = \frac{q}{t}$$

▪ measured in amperes (A)  $1\text{A} = \frac{1\text{C}}{1\text{s}}$

## \* Electrical resistance (symbol $R$ )

Why is it necessary to keep pushing the charges to make them move?

The electrons do not move unimpeded through a conductor. As they move they keep bumping into the ions of crystal lattice which either slows them down or bring them to rest.



♦ The **resistance ( $R$ )** is a measure of the degree to which the conductor impedes the flow of current.

♦ Resistance is measured in **Ohms ( $\Omega$ )**



## \* OHM'S LAW - Current, Voltage and Resistance

♥ DEF: Current through resistor (conductor) is proportional to potential difference on the resistor if the temperature of a resistor is constant (the resistance of a conductor is constant).

$$I = \frac{V}{R}$$



### Example:

If a 3 volt flashlight bulb has a resistance of 9 ohms, how much current will it draw?

$$I = V / R = 3\text{ V} / 9\ \Omega = 1/3\ \text{Amps}$$

If a light bulb draws 2 A of current when connected to a 120 volt circuit, what is the resistance of the light bulb?

$$R = V / I = 120\text{ V} / 2\ \text{A} = 60\ \Omega$$

## \* Factors affecting resistance

Conductors, semiconductors and insulators differ in their resistance to current flow.

♥ DEF: The electrical resistance of a piece of material is defined by the ratio of the potential difference across the material to the current that flows through it.

$$R = \frac{V}{I}$$

- ♦ The units of resistance are volts per ampere ( $\text{VA}^{-1}$ ).
- ♦ However, a separate SI unit called the ohm  $\Omega$  is defined as the resistance through which a current of 1 A flows when a potential difference of 1 V is applied.

## Wires, wires, wires

As you are going to see, the resistance of a wire can be completely ignored – if it is a thin wire connecting two, three or more resistors, or becoming very important if it is a long, long wire as in the case of iron, washing machine, toaster ....., where it becomes resistor itself.

The resistance of a conducting wire depends on four main factors:

• length • cross-sectional area • resistivity • temperature

### • Cross Sectional Area ( $A$ )

The cross-sectional area of a conductor (thickness) is similar to the cross section of a hallway. If the hall is very wide, it will allow a high current through it, while a narrow hall would be difficult to get through. Notice that the electrons seem to be moving at the same speed in each one but there are many more electrons in the larger wire. This results in a larger current which leads us to say that the resistance is less in a wire with a larger cross sectional area.

### • Length of the Conductor ( $L$ )

The length of a conductor is similar to the length of a hallway. A shorter hallway will result in less collisions than a longer one.

### • Temperature

To understand the effect of temperature you must picture what happens in a conductor as it is heated. Heat on the atomic or molecular scale is a direct representation of the vibration of the atoms or molecules. Higher temperature means more vibrations. In a cold wire ions in crystal lattice are not vibrating much so the electrons can run between them fairly rapidly. As the conductor heats up, the ions start vibrating. As their motion becomes more erratic they are more likely to get in the way and disrupt the flow of the electrons. As a result, the higher the temperature, the higher the resistance.

At extremely low temperatures, some materials, known as superconductors, have no measurable resistance. This is called superconductivity. Gradually, we are creating materials that become superconductors at higher temperatures and the race is on to find or create materials that superconduct at room temperature. We are painfully far away from the finish line.

### • Material used - resistivity

The resistivity,  $\rho$  (the Greek letter rho), is a value that only depends on the material being used. It is tabulated and you can find it in the books. For example, gold would have a lower value than lead or zinc, because it is a better conductor than they are.

♦ The unit is  $\Omega \cdot \text{m}$ .

♥ Resistance of a wire when the temperature is kept constant is:

$$R = \rho \frac{L}{A}$$

- In conclusion, we could say that a short fat cold wire makes the best conductor.
- If you double the length of a wire, you will double the resistance of the wire.

- If you double the cross sectional area of a wire you will cut its resistance in half.

### Example

A copper wire has a length of 1.60 m and a diameter of 1.00 mm. If the wire is connected to a 1.5-volt battery, how much current flows through the wire?

$L = 1.60 \text{ m}$ .

$r = 0.500 \text{ mm}$

$\rho = 1.72 \times 10^{-8} \Omega \text{m}$ , copper - books

$R = r L/A = (1.72 \times 10^{-8})(1.60)/(7.9 \times 10^{-7}) = 3.50 \Omega$

$I = V/R = 1.5/3.5 = 0.428 \text{ A}$

### \* Power dissipation in resistors

♥ DEF: Electric power is the rate at which energy is supplied to or used by a device.

♥ DEF: Power is the rate at which electric energy is converted into another form such as mechanical energy, heat, or light.

When a current is flowing through a load such as a resistor, it **dissipates energy in it**. In collision with lattice ions electrons' kinetic energy is transferred to the ions, and as a result the amplitude of vibrations of the ions increases and therefore the temperature of the device increases.

That thermal energy (internal energy) is then transferred as heat (to the air, food, hair etc.) by convection, or radiated as light (electric bulb).

Where is that energy coming from?

This energy is equal to the potential energy lost by the charge as it moves through the potential difference that exists between the terminals of the load.

- Power is measured in J/ scaled watts W.

If a vacuum cleaner has a power rating of 500 W, it means it is converting electrical energy to mechanical, sound and heat energy at the rate of 500 J/s. A 60 W light globe converts electrical energy to light and heat energy at the rate of 60 J/s.

### \* Deriving expressions for determining power

Basic definition of power:  $P = \frac{W}{t}$

Remember:  $W = qV \rightarrow P = qV/t$  and  $I = q/t$ , so

$$P = IV$$

$$P = V^2/R = I^2 R \quad 1W = \frac{1J}{1s} = 1A \cdot 1V$$

In USA you can not get direct information on power of appliance you buy.

Look at your hair dryer. If label says "10 A", that means that the power of the hair dryer is  $10 \times 120 = 1200 \text{ W}$ , or 1.2 kW (using a standard US 120 V outlet).

Comparison of US and other countries that use voltage of 240 V.

As the power of appliances is the roughly the same, the appliances in USA have to draw a greater current, hence have to have less resistance. As the consequence the wires (both used for connecting and in appliances) are thicker in USA.

example

How much current is drawn by a 60 Watt light bulb connected to a 120 V power line?

$$P = 60 \text{ W} = IV = I \times 120 \quad \text{so } I = 0.5 \text{ A}$$

What is the resistance of the bulb?

$$I = V/R \quad R = V/I = 120 \text{ V}/0.5 \text{ A} \quad R = 240 \Omega$$

### \* Paying for electricity

You pay for the total amount of electrical energy (not power) that is used each month

In Irving the cost of electric energy used is 14 ¢ per kilowatt-hour.

How do we get kilowatt-hour and what is that?

Power = energy/time

Energy = power x time, so energy can be expressed in units watts x second what is simply a joule.

Physicists measure energy in joules, but utility companies customarily charge energy in units of kilowatt-hours (kW h), where

$$\text{Kilowatt-hour (kWh)} = 10^3 \text{ W} \times 3600 \text{ s}$$

$$1 \text{ W} \times 1 \text{ s} = 1 \text{ J}$$

$$1 \text{ kWh} = 3.6 \times 10^6 \text{ J}$$

### \$\$\$ example \$\$\$

At a rate of 14 cents per kWh, how much does it cost to keep a 100 W light bulb on for one day?

energy (kWh) = power (kW) x time (h)

energy (kWh) = 0.1 kW x 24 h = 2.4 kWh

cost / day = 2.4 kWh x 14 cents/kWh = 33.6 ¢

◇ for one month that amounts to \$ 10.1.

### \* Direct Current (DC) electric circuits

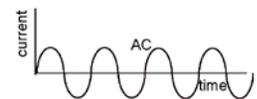
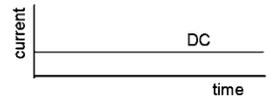
a circuit containing a battery is a DC circuit in a DC circuit the current always flows in the **same direction**.

The direction of the current depends on how you connect the battery Either way the bulb will be on.

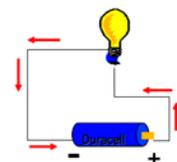
a circuit must provide a closed path for the current to circulate around

when the electrons pass through the light bulb they loose some of their energy → the conductor (resistor) heats up

the battery is like a pump that re-energizes them each time they pass through it

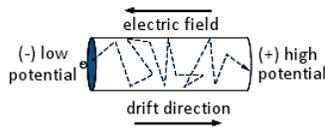


♥ DEF: The electrons go one way but the current flows the opposite to the direction that the electrons travel. That's convention.



### \* Drift speed

When a battery is connected across the ends of a metal wire, an electric field is produced in the wire. **All free electrons in the circuit start moving at the same time.** Free electrons are accelerated along their path reaching enormous speeds of about  $10^6 \text{ ms}^{-1}$ . They collide with positive ions of crystal lattice generating heat that causes the temperature of the metal to increase. After this event, they are again accelerated because of the electric field, until the next collision occurs. Due to the collisions with positive ions of crystal lattice, hence changing direction, it is estimated that the drift velocity is only a small fraction of a metre each second (about  $10^{-4} \text{ m s}^{-1}$ ).



example: in an el. circuit of a car, electrons have average drift speed of about 0.01 cm/s, so it takes ~ 3 hour for an electron to travel through 1m.

it's not even a snail's pace!!!!

The electricity that you get from the power company is not DC it is AC (alternating) created by an AC electric generator.

In an AC circuit the current reverses direction periodically

The current in AC electricity alternates in direction. The back-and-forth motion occurs at freq. of 50 or 60 Hz, depending on the electrical system of the country.

!!!!!! the source of electrons is wire itself – free electrons in it !!!!!

If you are jolted by electric shock, electrons making up the current in your body originate in your body. They do NOT come from the wire through your body into the ground. Alternating electric field causes electrons to vibrate. Small vibrations – tingle; large vibrations can be fatal.

- How does the voltage and current change in time?

DC does not change direction over time;

the actual voltage in a 120-V AC circuit varies between +170V and -170V peaks.

### \* Electromotive force (emf – $\epsilon$ or E)

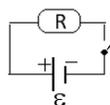
We have defined potential difference as the amount of work that has to be done to move a unit positive charge from one point to the other in an electric field.

$$\Delta V = \frac{W}{q} = \frac{\Delta U}{q}$$

A battery or an electric generator that transforms one type of energy into electric energy is called **source of electromotive force**

\* DEF: emf ( $\epsilon$ ) of the source is the potential difference between the terminals when NO current flows to an external circuit.

IT IS A VOLTAGE NOT A FORCE.



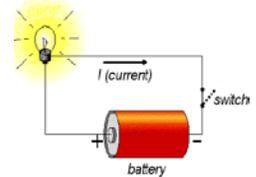
In the true sense, electromotive force (emf) is the **work (energy) per unit charge made available by an electrical source.**

### \* D.C. circuit analysis

Electric Circuits: Any path along which electrons can flow is a circuit. For a continuous flow of electrons, there must be a complete circuit with no gaps. A gap is usually provided by an electric switch that can be opened or closed to either cut off or allow electron flow.

An electric circuit has three essential components

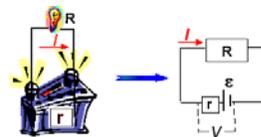
1. A source of emf.
2. A conducting pathway obtained by conducting wires or some alternative.
3. A load to consume energy such as a filament globe, other resistors and electronic components.



When the switch is closed, a current exists almost immediately in all circuit. The current does not "pile up" anywhere but flows through the whole circuit. Electrons in all circuit begin to move at once. Eventually the electrons move all the way around the circuit. A break anywhere in the path results in an open circuit, and the flow of electrons ceases.

### \* Terminal voltage, emf and internal resistance

In the circuit the total energy supplied is determined by the value of the emf. When electrons flow around a circuit, they gain potential energy in the cell and then lose the energy in the resistors. In a closed circuits charge must flow between the electrodes of the battery and there is always some hindrance to completely free flow. So when the current  $I$  is drawn from the battery there is some resistance called INTERNAL RESISTANCE ( $r$ ) of the battery causing the voltage between terminals to drop below the maximum value specified by the battery's emf.



Thus the **TERMINAL VOLTAGE** (the actual voltage delivered) is:

$$V = \epsilon - Ir$$

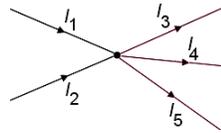
In the mid-nineteenth century, G.R. Kirchoff (1824-1887) stated two simple rules using the laws of conservation of energy and charge to help in the analysis of direct current circuits.

These rules are called **Kirchoff's rules**.

**\* 1. Junction rule – conservation of charge.**

The sum of the currents flowing into a point in a circuit equals the sum of the currents flowing out at that point.

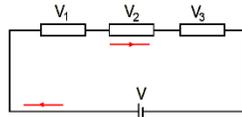
$$I_1 + I_2 = I_3 + I_4 + I_5$$



**\* 2. loop rule – conservation of energy principle: Energy supplied equals the energy released in this closed path**

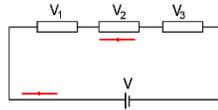
In a closed loop, the sum of the emfs equals the sum of the potential drops

$$V = V_1 + V_2 + V_3$$

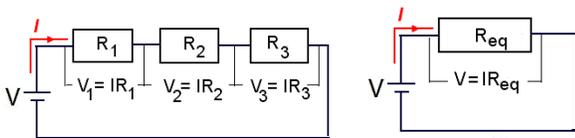


**\* Resistors in Series**

- connected in such a way that all components have the same current through them.
- Burning out of one of the lamp filaments or simply opening the switch could cause such a break.



♥ Equivalent or total or effective or resistance is the one that could replace all resistors resulting in the same current.



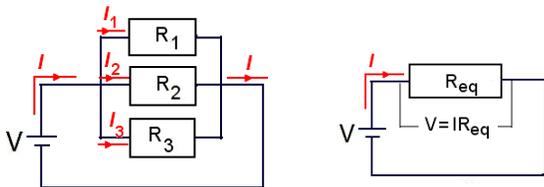
$$R_{eq} = R_1 + R_2 + R_3$$

logic: the total or effective resistance would have length  $L_1 + L_2 + L_3$  and resistance is proportional to the length



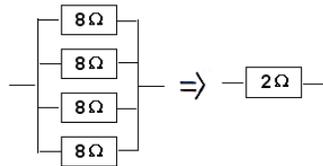
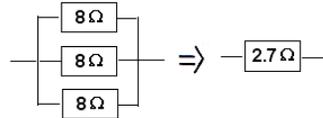
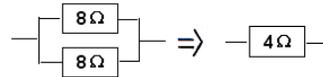
**\* Resistors in Parallel**

- Electric devices connected in parallel are connected to the same two points of an electric circuit, so all components have the same potential difference across them.
- The current flowing into the point of splitting is equal to the sum of the currents flowing out at that point:  $I = I_1 + I_2 + I_3$ .

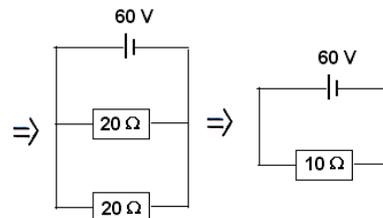
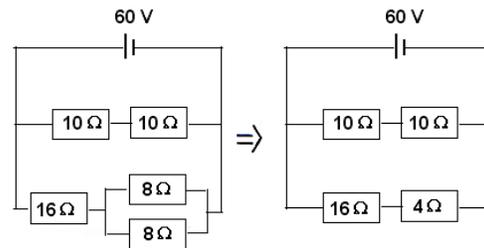
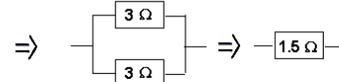
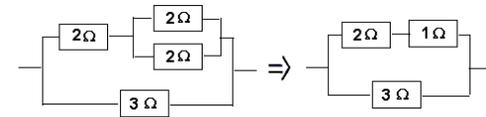
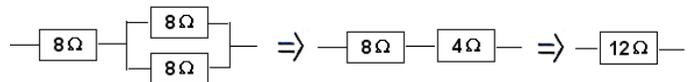


$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

- A break in any one path does not interrupt the flow of charge in the other paths. Each device operates independently of the other devices. The greater resistance, the smaller current.

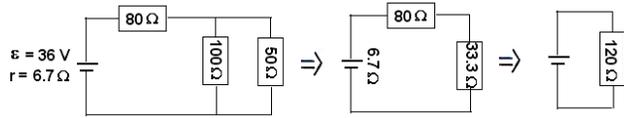


**\* Resistors in compound circuits**



Now you can calculate current, potential drop and power dissipated through each resistor

example: Find power of the source, current in each resistor, terminal potential, potential drop across each resistor and power dissipated in each resistor.



$R_{eq} = 120 \Omega$

$I = \epsilon / R_{eq} = 0.3 A$

terminal potential:  $V = \epsilon - Ir = 36 - 0.3 \times 6.7 = 34 V$

current through resistors 100Ω and 50Ω :  $I = I_1 + I_2 \quad I_1 R_1 = I_2 R_2$

$0.3 = I_1 + I_2 \quad 100 I_1 = 50 I_2 \quad \rightarrow I_1 = 0.1 A \quad I_2 = 0.2 A$

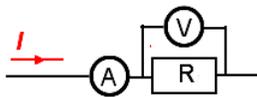
	potential drops $V = IR$	power dissipated $P = IV$
80 Ω	$0.3 \times 80 = 24 V$	$0.3 \times 24 = 7.2 W$
100 Ω	$0.1 \times 100 = 10 V$	$0.1 \times 10 = 1 W$
50 Ω	$0.2 \times 50 = 10 V$	$0.2 \times 10 = 2 W$
6.7 Ω	$0.3 \times 6.7 = 2 V$	$0.3 \times 2 = 0.6 W$

$\epsilon = \Sigma \text{ all potential drops: } 36 V = 2 V + 24 V + 10 V$

power dissipated in the circuit = power of the source  
 $0.6 + 2 + 1 + 7.2 = 0.3 \times 36$

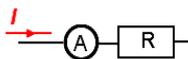
**\* Ammeters and voltmeters**

In practical use, we need to be able to measure currents through components and voltages across various components in electrical circuits. To do this, we use **AMMETERS** and **VOLTMETERS**.

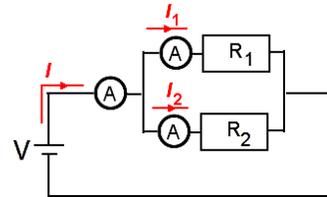
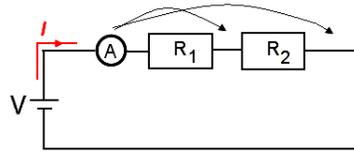


**♥ An ammeter – measures current passing through it**

- is **always connected in series** with a component we want to measure in order that whatever current passes through the component also passes the ammeter.

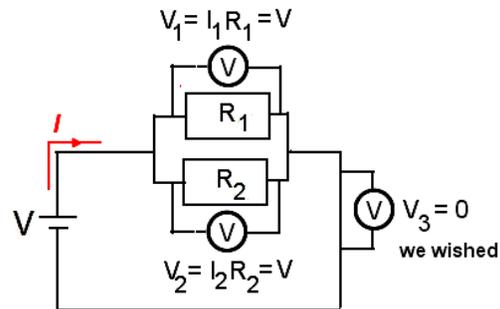
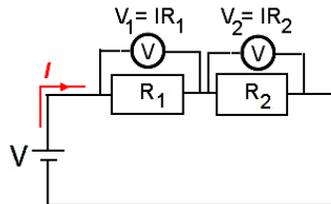
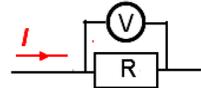


- has a very low resistance compared with the resistance of the circuit so that it will not alter the current the current being measured.
- would ideally have no resistance with no potential difference across it so no energy would be dissipated in it.



**♥ A voltmeter – measures voltage drop between two points**

- is **always connected** across a device (in parallel).
- has a very high resistance so that it takes very little current from the device whose potential difference is being measured.
- an ideal voltmeter would have infinite resistance with no current passing through it and no energy would be dissipated in it.



**Ohm's Law & Power Practice Problems – SHOW YOUR WORK**

1. A toaster oven is plugged into an outlet that provides a voltage difference of 120 V. What power does the oven use if the current is 10A?
2. A VCR that is not playing still uses 10.0 W of power. What is the current if the VCR is plugged into a 120 V electric outlet?
3. A flashlight bulb uses 2.4 W of power when the current in the bulb is 0.8 A. What is the voltage difference?
4. A refrigerator operates on average for 10.0 h a day. If the power rating of the refrigerator is 700 W, how much electrical energy does the refrigerator use in 1 day? (make sure to convert to kW)
5. A TV with a power rating of 200 W uses 0.8 kWh in one day. For how many hours was the TV on during this day?
6. Calculate the voltage difference in a circuit with a resistance of 25  $\Omega$  if the current in the circuit is 0.5 A.
7. A current of 0.5 A flows in a 60 W light bulb when the voltage difference between the ends of the filament is 120 V. What is the resistance of the filament?
8. A toy car with a resistance of 20  $\Omega$  is connected to a 3 V battery. How much current flows in the car?
9. The current flowing in an appliance connected to a 120 V source is 2 A. How many kilowatt-hours of electrical energy does the appliance use in 4 h? (2 equations used & convert watts to kW)
10. A calculator uses 9 V battery & draws 0.1 A of current. How much power does it use?



8. How much current, in amperes, is in a lightning stroke that lasts 0.05 second and transfers 100 coulombs?
  
  
  
  
  
  
  
  
  
  
9. Calculate the resistance of the filament in a light bulb that carries 0.4 A when 3.0 V is impressed across it.
  
  
  
  
  
  
  
  
  
  
10. Electric socks, popular in cold weather, have a 90-ohm heating element that is powered by a 9-volt battery. How much current warms your feet?
  
  
  
  
  
  
  
  
  
  
11. Calculate the current of a lightning bolt that delivers a charge of 35 coulombs to the ground in a time of 1/1000 second.
  
  
  
  
  
  
  
  
  
  
12. Calculate the current where 10 coulombs of charge pass a point in 5 seconds.
  
  
  
  
  
  
  
  
  
  
13. Two light bulbs designed for 120-V use are rated at 40W and 60W. Which light bulb has the greater filament resistance? Why?
  
  
  
  
  
  
  
  
  
  
14. A battery does 18 joules of work on 3 coulombs of charge. What voltage does it supply?
  
  
  
  
  
  
  
  
  
  
15. A power line with a resistance of 2 ohms has a current of 80 A in it. The power dissipated in the line is

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25. A calculator uses 9 V battery & draws 0.1 A of current. How much power does it use?
26. A battery causes 250 mA to flow when it is applied to a light bulb with a resistance of 50 ohms. How much current would flow if the same source were applied to a 12 ohm resistor?
27. A 160 ohm load is connected to a 325 volt source. If the source voltage increases to 425 volts, what value must the load resistance be changed to keep the current flow the same?
28. A 100 W light bulb draws 833 mA when the rated voltage is applied. What is the rated voltage?
29. A 1.5 k $\Omega$  resistor rated at 250 mW will be damaged if 18 V is applied across it. T/F

30. A  $30\text{ k}\Omega$  resistor rated at  $\frac{1}{2}$  Watt will be damaged if a current flow of  $4.5\text{ mA}$  is flowing through it. T/F
31. A  $1\text{ Watt}$ ,  $220\ \Omega$  resistor has  $14\text{ V}$  applied. The resistor will exceed the power rating and be damaged. T/F
32. A  $\frac{1}{8}\text{ Watt}$   $50\text{ k}\Omega$  resistor has  $70\text{ V}$  applied. The resistor will exceed the power rating and be damaged. T/F
33. Calculate the resistance of a wire if  $0.5\text{ V}$  across it causes a current of  $2.5\text{ A}$  to flow.
34. Calculate current flow through a  $20\text{ M}\Omega$  resistor connected across a  $100\text{ kV}$  power supply.
35. An iron draws  $6.0\text{ A}$  of current when operating in a country with a mains supply of  $120\text{ V}$ . Calculate the resistance of the iron?
36. An electrical appliance is rated as  $2.5\text{ kW}$ ,  $240\text{ V}$ .  
(a) Determine the current needed for it to operate.  
(b) Calculate the energy it would consume in  $2.0$  hours.
37. Calculate the current in a  $48\text{-V}$  battery that powers a pair of  $30\ \Omega$  resistors connected in series.
38. Calculate the current in a  $48\text{-V}$  battery that powers a pair of  $30\ \Omega$  resistors connected in parallel.

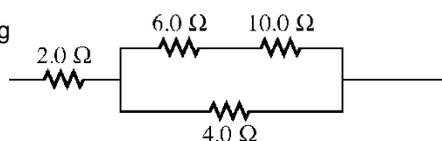
39. The following three appliances are connected in series to a 120 V house circuit: a toaster, 1200 W; a coffee pot, 750 W; and a microwave,  $6.0 \times 10^2$  W. If all were operated at the same time, what total current would they draw?

40. Three resistors with values of  $3.0 \Omega$ ,  $6.0 \Omega$ , and  $12 \Omega$  are connected in parallel. What is the equivalent resistance of this combination?

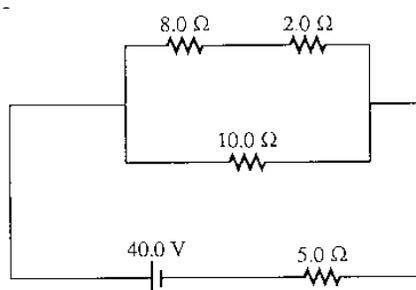
41. Determine the equivalent resistance when  $12 \Omega$ ,  $6 \Omega$  and  $4 \Omega$  are placed in  
 (a) series  
 (b) parallel

42. Two resistors with values of  $6.0 \Omega$  and  $12 \Omega$  are connected in parallel. This combination is connected in series with a  $4.0 \Omega$  resistor. What is the overall resistance of this combination?

43. What is the equivalent resistance for the resistors in the fig



44. What is the equivalent resistance for the resistors in the figure



45. A dry cell has an internal resistance of  $1.50 \Omega$ . A resistor of  $12.0 \Omega$  is connected in series with the dry cell. If the potential difference across the  $12.0 \Omega$  resistor is  $1.20 \text{ V}$ , calculate the emf of the cell.

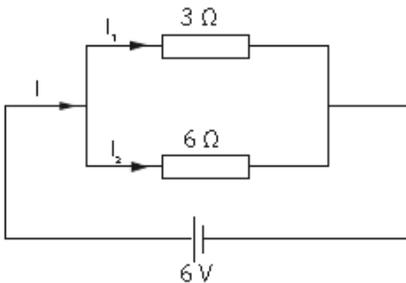
46. When a dry cell is connected to a circuit with a load resistor of  $4.0 \Omega$ , there is a terminal voltage of  $1.3 \text{ V}$ . When the load resistor is changed to  $12 \Omega$ , the terminal voltage is found to be  $1.45 \text{ V}$ .

Calculate

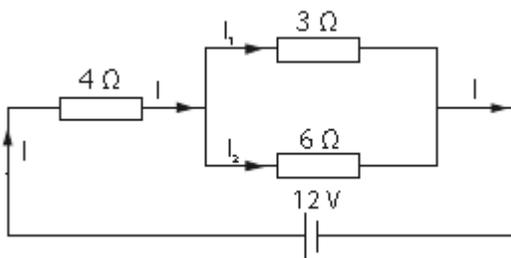
- the emf of the cell.
- the internal resistance of the cell.

47. From the diagram given in the Figure below, calculate

- the effective resistance of the circuit,
- the current flowing in the main circuit,
- the current in each resistor.

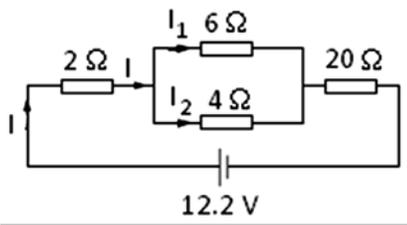


48. From the diagram given in the figure (below), calculate



- the total resistance of the circuit
- the current flowing in the main circuit
- the current in each resistor

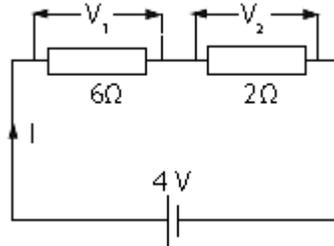
49. The diagram shows resistances joined in a compound circuit.



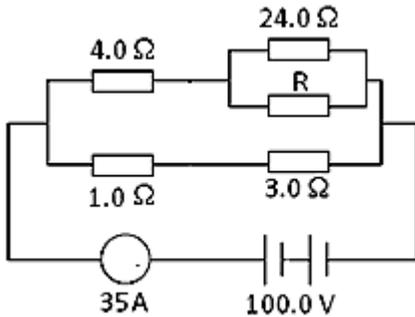
- (a) Determine the total resistance of the circuit.
- (b) Calculate current flows through the 2.0 Ω resistor.
- (c) Deduce the potential difference across the 20.0 Ω resistor.
- (d) Determine is the potential difference across the 6.0 Ω resistor.
- (e) Calculate is the current through the 4.0 Ω resistor.

50. From the diagram given in the Figure below of a potential divider, calculate

- (a) the effective resistance of the circuit
- (b) the current flowing
- (c) the potential difference across each resistor

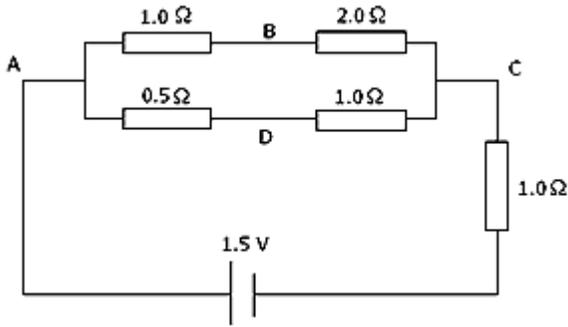


501. The circuit below refers to the following questions:



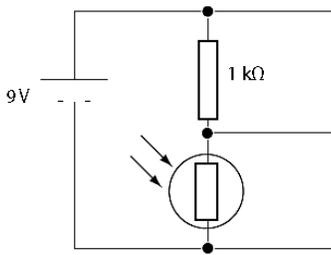
Determine the current flowing through R, and the value of resistor R.

52. The diagram shows a typical circuit.

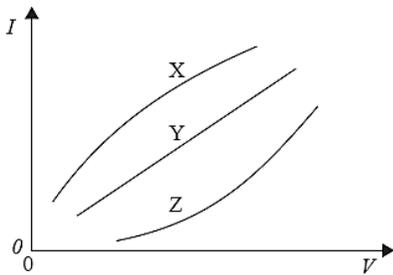


- (a) Determine the effective resistance of the whole circuit.
- (b) Determine the currents flowing in each network resistor.
- (c) Determine the potential differences  $V_{AB}$  and  $V_{AD}$ .
- (d) Determine the potential difference between B and D.

53. Determine the resistance of the LDR in the diagram below if a current of 4.5 mA is flowing in the circuit.



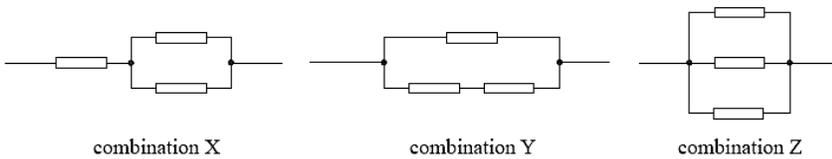
54. The graph below shows the variation with voltage  $V$  of the current  $I$  in three resistors X, Y and Z.



Which of the following corresponds to resistors for which the resistance increases with increasing current?

- A. X only
- B. Z only
- C. X and Z
- D. Y and Z

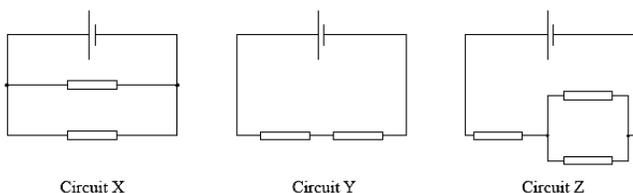
55. The diagrams below show combinations X, Y and Z of three resistors, each resistor having the same resistance.



Which one of the following shows the resistances of the combinations in increasing order of magnitude?

	lowest	→	highest
A.	Y	X	Z
B.	Z	X	Y
C.	X	Y	Z
D.	Z	Y	X

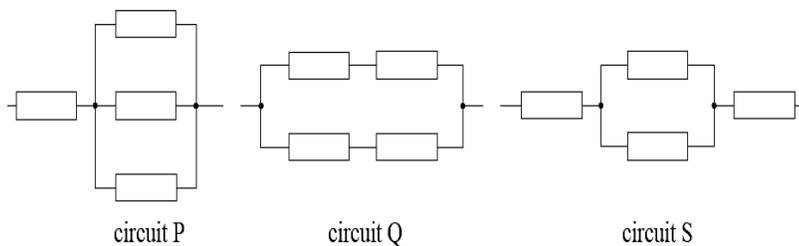
56. In the circuits below, the batteries each have the same voltage. All the resistors have the same resistance.



Which of the following gives the current through the cells in order of increasing magnitude?

	Lowest current	→	Highest current
A.	X	Y	Z
B.	Z	X	Y
C.	Y	Z	X
D.	Y	X	Z

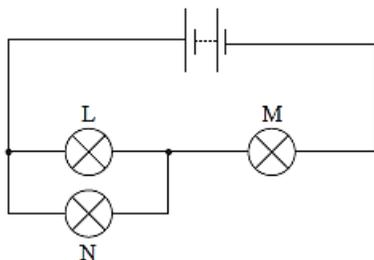
57. The resistors in each of the circuits shown below each have the same resistance.



Which of the following gives the circuits in order of increasing total resistance?

- A. P Q S
- B. Q P S
- C. S Q P
- D. P S Q

58. In the circuit below, the battery has negligible internal resistance. Lamps L, M and N which have different resistance are connected as shown.



Which **one** of the following is always true?

- A. Lamps L and N have the same current through them.
- B. Lamps L and M have the same current through them.
- C. Lamps L and N have the same potential difference across them.
- D. Lamps L and M have the same potential difference across them.

59. A DC electric motor converts 75 % of the input electrical energy to mechanical energy. The remaining 25 % is
- A. dissipated as heat energy.
  - B. returned to the battery.
  - C. used to maintain the potential difference of the battery.
  - D. converted to electrical potential energy.
60. The element of an electric heater has a resistance  $R$  when in operation. What is the resistance of a second heater that has a power output three times as large at the same operating voltage?
- A.  $R/9$
  - B.  $R/3$
  - C.  $3R$
  - D.  $9R$